



Contents lists available at ScienceDirect

# Environmental Innovation and Societal Transitions

journal homepage: [www.elsevier.com/locate/eist](http://www.elsevier.com/locate/eist)



## Understanding the drivers of fleet emission reduction activities of the German car manufacturers



Christoph Mazur<sup>a,b,e,\*</sup>, Marcello Contestabile<sup>c</sup>,  
Gregory J. Offer<sup>d</sup>, N.P. Brandon<sup>b</sup>

<sup>a</sup> Grantham Institute – Climate Change and the Environment, Imperial College London, SW7 2AZ, UK

<sup>b</sup> Earth Science and Engineering Department, Imperial College London, London SW7 2AZ, UK

<sup>c</sup> Centre for Environmental Policy, Imperial College London, London SW7 2AZ, UK

<sup>d</sup> Mechanical Engineering Department, Imperial College London, London SW7 2AZ, UK

<sup>e</sup> Energy Futures Laboratory, Imperial College London, London SW7 2AZ, UK

### ARTICLE INFO

#### Article history:

Received 6 February 2015

Received in revised form 12 April 2015

Accepted 14 June 2015

Available online 2 July 2015

#### Keywords:

Industry incumbents

Transitions

Policy making

Micro-level

Electric vehicles

### ABSTRACT

The current mobility system, dominated by fossil fuel powered automobiles, is under increasing pressure due to its environmental impact. To address this issue there is a need for a transition of the system towards one that is more sustainable, including the introduction of car technologies that allow a decrease in fuel consumption and the substitution of fossil fuels as primary energy source. Due to the stability of the current automotive industry and the dominance of the internal combustion engine technology, it is expected that the incumbent firms and their activities will play a crucial role in the transition. Policy makers have therefore introduced a variety of policies to encourage the industry to provide suitable solutions. We have conducted a micro-level analysis of how the three main German car manufacturers have changed their activities in the field of low emission vehicle technologies in response to national/international events and policy making. Our analysis suggests that policy makers only have limited influence on the type of disruptive solution that is chosen by these individual companies and that activities related to solutions that were not familiar to the individual car manufacturer were mainly induced by internal or

\* Corresponding author at: Grantham Institute – Climate Change and the Environment, Imperial College London, SW7 2AZ, UK. Tel.: +44 7572270049.

E-mail address: [christoph.mazur@imperial.ac.uk](mailto:christoph.mazur@imperial.ac.uk) (C. Mazur).

<http://dx.doi.org/10.1016/j.eist.2015.06.002>

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external champions. Still, while the existence of regulatory policies allowed such activities to succeed, on its own it only encouraged the industry to work on incremental solutions based upon the knowledge already possessed.

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## 1. Introduction

Over the last few decades the automotive regime has been experiencing a number of challenges, both changing customer expectations and needs, particularly their perception of oil supply uncertainty and price volatility, and also governmental and regional policies driven by climate change and local air quality issues. As automobiles are responsible for a large fraction of total energy-related GHG emissions (IEA, 2010; WEC, 2011) the on-going discussions on fuel efficiency and emission reduction goals has led, and will lead, to changes in behaviour, strategies and products in the automotive industry.

One way of addressing these pressures is the introduction of technologies such as hybrid, battery and fuel cell electric vehicles (Howey and Martinez-Botas, 2010; IEA, 2010; Offer et al., 2010). It is argued that the whole spectrum of electric vehicle technologies is likely to be needed in a future decarbonised road transport system, each playing a different role (Contestabile et al., 2011; IEA, 2010; McKinsey & Company, 2010). As a result scenarios, such as those analysed by the IEA and World Energy Council, are used to highlight futures with a diffusion of those different vehicle propulsion technologies that may lead to the change of whole socio-technical systems (IEA, 2010; Vallejo et al., 2013; WEC, 2011). Hence the diffusion of a new vehicle propulsion technology is potentially a complex systemic problem, subject to issues such as technology lock-ins (Unruh, 2000, 2002).

While policy makers have tried to create policies leading to futures that are favourable for their countries, economies and citizens, the response of the system is not always as expected. And even now in the current transition towards electric cars the diffusion of low emission vehicles is not happening as fast as it was aimed for by policy makers. This can be explained by the stability of the system and especially the role of the automotive industry that is strongly embedded in the current private car transport regime (Wells and Nieuwenhuis, 2012). Because of that stability we assume that the change towards electric cars will happen at least with the participation of the current incumbent automotive manufacturers, if not even be executed entirely by them. Even in the case of the electric vehicle manufacturer Tesla we would argue that it is actually an 'offspring' of the existing automotive regime, as it strongly relies on an employee base that has been hired from the automotive industry regime except for the engine engineers. Additionally they take advantage of the existing automotive supply chains. Using the typology of stereotypic historical transition pathways (Geels and Schot, 2007), this would imply a transformation or a reconfiguration pathway where the current regime players – namely the automotive industry – still play an important role in a future regime where electric vehicles dominate (Wells and Nieuwenhuis, 2012). Hence as a result this paper focuses on a transition towards electric vehicles that is executed by the existing automotive industry. This is confirmed by the fact that this industry has presented different types of low emission vehicles in the past. Not only have there been a vast number of low emission vehicles in the past, such as the electric EV-1 by GM in 1996 and the fuel cell vehicle Necar by Daimler in 1994 to name two early ones. But recently we are observing the introduction of various low emission vehicles into the mass market, such as the Tesla S by Tesla Motors, the i3 by BMW, the Leaf by Nissan or, before that, the Prius hybrid vehicle by Toyota.

A number of studies (Bakker and Farla, 2015; Bakker et al., 2012a,b; Geels, 2012; Köhler et al., 2013; Mazur et al., 2015; Wiesenthal et al., 2010) have emphasised the strong role of policy in leading to this development. Other studies (Farla et al., 2012; Mazur et al., 2015; Penna and Geels, 2012; Wells and Nieuwenhuis, 2012; Wesseling et al., 2013) have also emphasised the importance of the existing automotive industry in delivering this transition, implying that the understanding of the micro-level activities of this industry is crucial if policy makers are intending to design policies that are able to deliver the desired environmental objectives.

To understand what events have particularly influenced the automotive industry's activities regarding vehicle fleet emission reduction technology, we have conducted a study of the micro-level activities of the German car manufacturers, linking these with historical events at the regime and landscape level. The goal is to identify patterns in the companies' behaviour.

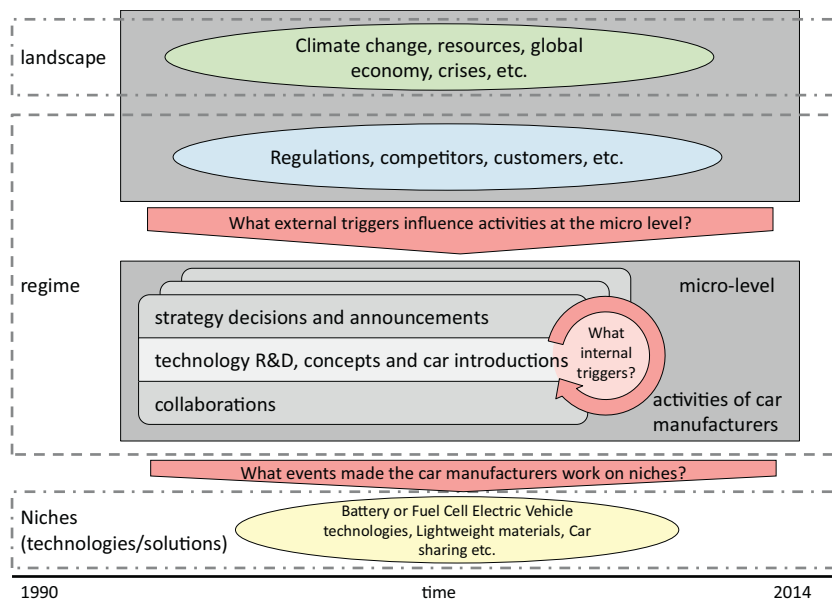
## 2. Methodology

### 2.1. Analytical framework

In order to analyse the behaviour of the automotive industry in response to various types of events and pressures, we have developed the framework illustrated in Fig. 1. We have built upon methodologies from a number of studies (Budde et al., 2012; Konrad et al., 2012) addressing the effects of expectations on strategy and micro-level activities within the industry. Moreover, the framework's structure is based upon the multi-level perspective on socio-technical transitions (Geels, 2005; Rip and Kemp, 1998) that differentiates between landscape, regime and niche levels, and describes transitions as the result of interactions between these levels. In our framework the activities of the automotive industry are put in relation to events on the regime and landscape level – this can also include expectations.

The framework is then used as a basis to create narratives on the industry as commonly done in previous research (Augenstein, 2015; Budde et al., 2012; Konrad et al., 2012; Nykvist and Nilsson, 2015) addressing the role of the automotive industry in sustainability transitions.

We focus our analysis on the three main car manufacturers in Germany (Daimler, BMW, Volkswagen). They are part of the current regime and conduct different activities in order to respond to company external pressures. These activities are differentiated in the framework between (1) strategy decisions and announcements, (2) research and development activities as well as introduction of efficiency improvement technologies, and the (3) collaboration with other companies in these domains.



**Fig. 1.** Overview of analytical framework (based upon Budde et al., 2012 and Konrad et al., 2012). (For interpretation of the references to colour in this sentence, the reader is referred to the web version of the article.)

Strategy decisions and announcements include new, revised or abandoned technology targets for the achievement of efficiency improvements and related sales targets. Technology related activities can include launches, changes or discontinuation of certain technologies, establishing a new research group, presenting a prototype and launching a vehicle on the market. Finally, collaboration activities include instances where new collaborations are set up or cancelled, companies acquired or external actors approached the company.

These activities are then put into relation with events on the regime and landscape level. For this to be possible, the framework needs to also cover the regime and landscape around the incumbent players and their evolution over time. In particular, the landscape level focuses on aspects such as economic development, fuel prices and climate change pressures, while the regime level illustrates international and national policies, and consumer's and competitors' behaviour, similar to past studies (Budde et al., 2012) conducted in this field.

In addition to the above, the niche level offers a possible pool of alternative and disruptive solutions to the organisations. In certain cases the car manufacturers can interact with these technology niches, meaning that they can conduct activities that have the aim to internalise these disruptive solutions. Alternatively they can respond to pressure by just introducing incremental improvements.

This study aims to identify what events on the landscape and regime level, and on the micro-level, encouraged the car manufacturers to internalise these niches (see red arrows in Fig. 1).

## 2.2. Design of the study

In order to conduct the study, first an extensive review of the literature on the micro-level activities as well as on events that occurred on the landscape and regime level since 1990 was conducted. The type of information collected was defined by the analytical framework and focused on activities relevant to the reduction of fleet emissions. The information gathered was then used to build a set of historical timelines that are presented in Section 2.3; the set consists of one timeline showing major events on landscape and regime levels in which the car manufacturers are embedded, and three micro-level timelines, one for each German car manufacturer studied. The content of the timelines are motivated by the analytical framework and so constructed allow the comparative study of three companies that are all in the same environment and are all affected by the same company external events.

To this end, we then conducted an analysis where the timeline for each car manufacturer was examined for significant changes in the firm's activities, with a focus on those activities involving major interactions with niche solutions. Once this was done the landscape/regime timeline was examined for events that had occurred during or before this activity, in order to find potential causal links between the landscape/regime timeline and the car manufacturer's. The focus was put on activities such as research, development and commercialisation of technologies and solutions that contributed to lower emissions.

Based upon this approach a narrative for each car manufacturer is created and presented in Section 3.

## 2.3. Data

Alike similar studies (Budde et al., 2012; Konrad et al., 2012; Wesseling et al., 2013) that looked at the behaviour of the automotive industry, the data needed for our study are obtained using a mixture of methods, including an extensive review and analysis of scientific literature and discourses, and then validated through interactions with industry experts. As already outlined by other studies (Budde et al., 2012) such a meticulous approach is necessary, as the automotive industry normally does not disclose the reasons for their activities.

Initially we reviewed the literature (Bakker and Budde, 2012; Bakker et al., 2012a,b; Budde et al., 2012; Collantes and Sperling, 2008; Dijk and Yarime, 2010; Hacker et al., 2009; IEA, 2012; Köhler et al., 2013; Konrad et al., 2012; Mazur et al., 2015; Wesseling et al., 2013, 2014) that provides insights into strategies and activities, technology trends and hypes, national and international policies, competitors' behaviours, economic pressures, fuel prices and infrastructures, and future expectations.

Subsequently we executed a discourse analysis of coverage in the mass media,<sup>1</sup> screening our selected sources for information on vehicle releases, strategic decisions and collaborations. For our analysis we selected those articles containing keywords such as “electric vehicle”, “hybrid”, “concept vehicle”, “fuel cell”, “battery”, etc. and those that dealt with major vehicle exhibitions such as the events held in Detroit, Geneva, Paris or Frankfurt.

Finally, annual reports of the three German car manufacturers were screened for information on vehicles releases, strategy decisions and low emission technologies. Here the environmental sections often offered insights into what technology solutions were preferred at given times.

The data above has been gathered for each year of the observed period of 1990–2014 and put into the timelines (see Figs. 3–8).

The timelines were presented at conferences attended by representatives of the automotive industry and were also – in private – discussed with experts.<sup>2</sup> This provided a form of validation of the data gathered and of the main causal relationships that we had derived from it; the latter is particularly important as the review of the literature and discourses we carried out does not in itself guarantee the validity of the causal relationships inferred.

In the following section, we provide simplified versions of the timelines above where we summarise the main disruptive events that led the car manufacturers to work on niche solutions.

### 3. Analysis

In the following a number of cases are outlined where various car manufacturers interact with niche technologies and solutions; these are put in relation with pressures the companies experienced at the time. In the analysis of the timelines, particular attention is paid to cases where companies have decided to do something new – something that went beyond their past technology path. This means that while continuous improvements in domains where the companies had already extensive knowledge, including efficiency improvements in combustion engines, are also discussed, the focus is put on events that led to the work on technologies that were step changes for the company. Following the analytical approach described, disruptive events were identified and then put in relation with changes at the regime and landscape level, in order to identify possible causal relationships.

In the following sections we provide narratives of the temporal evolution of the automotive regime and landscape in which the car manufacturers are embedded (see Fig. 2) and of the micro-level activities of the three main German car manufacturers.

#### 3.1. *The automotive regime and the landscape*

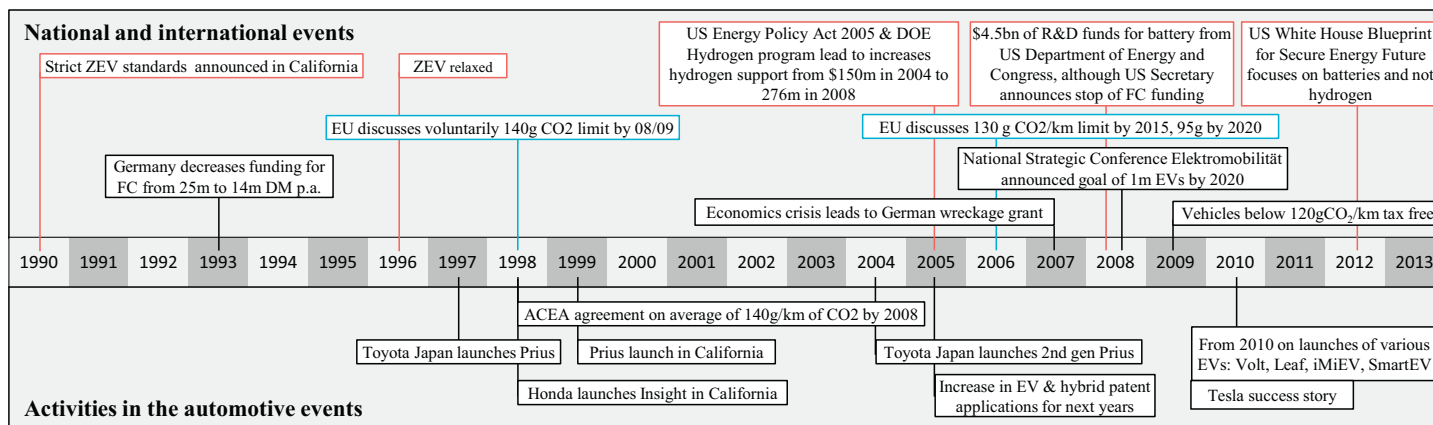
The Zero Emissions Vehicle (ZEV) initiative in California in 1990 was one of the first policy measures pushing towards electric vehicles (Budde et al., 2012; Collantes and Sperling, 2008). It encompassed a number of targets with regard to vehicle emissions as well as the market penetration of zero emission vehicles. Though it was only limited to California it had a significant impact on the US and the world. More than 10% of the US vehicle market was in California (National Automobile Dealers Association, 2014), and policy developments in California often moved to other States. Although it triggered a number of EV and FCEV prototypes being presented by the industry, it was then relaxed in 1996 as by then the original goals were no longer expected to be met (Budde et al., 2012).

Despite this, the ZEV initiative influenced policy makers worldwide, also in terms of technology choices (Budde et al., 2012, 2015). In the case of Germany, until the 1990s hydrogen fuel cell vehicles had been favoured by the government resulting in substantial funding for hydrogen and fuel cell research (Budde et al., 2012). As a result of the ZEV initiative, this changed and the interest diversified to include other technologies such as batteries (Budde et al., 2012). Then around 1996/97, at a time

<sup>1</sup> For mass media the study has focused on three major German quality newspapers, *Der Spiegel*, *Frankfurter Allgemeine Zeitung* and *Handelsblatt* (financial journal). For professional coverage we focused on the *VDI Nachrichten*, a journal for engineers and technical management. Furthermore, we looked at media such as *Autobild* and *Green Car Congress*.

<sup>2</sup> This included experts from the industry (BMW, Daimler, Audi) and experts from academia.

Fig. 2. Timeline for the automotive landscape and regime.



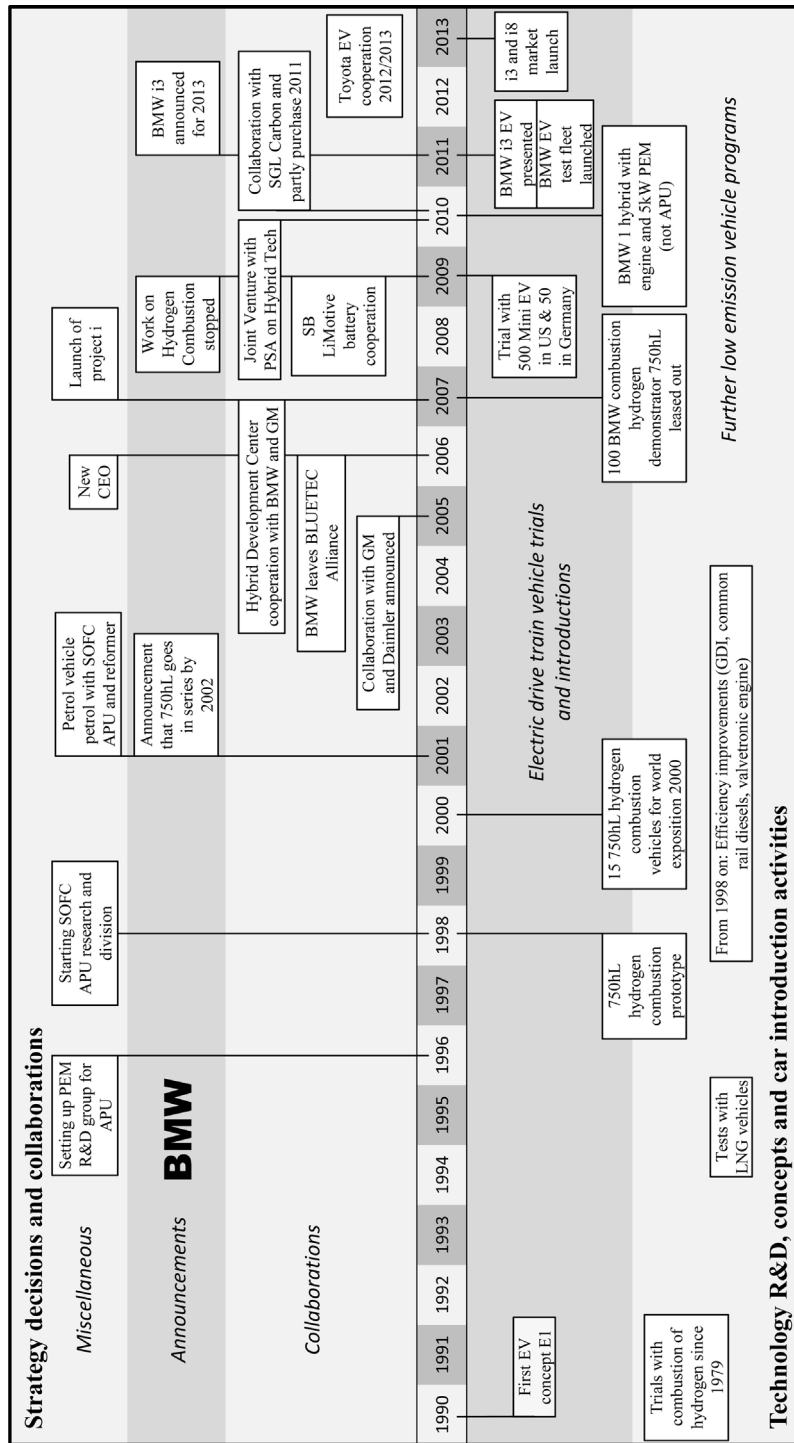


Fig. 3. Timeline for BMW.

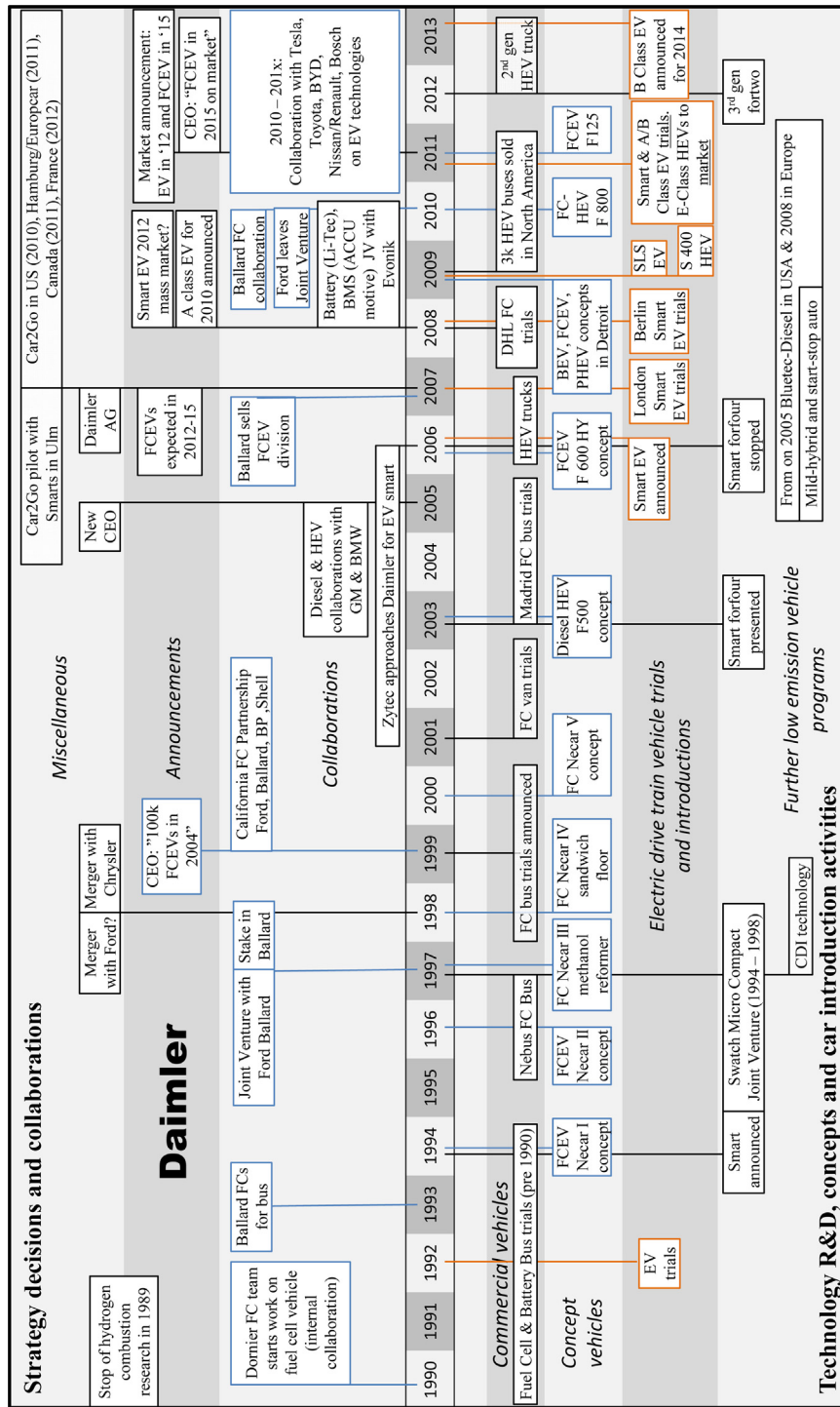


Fig. 4. Timeline for Daimler.



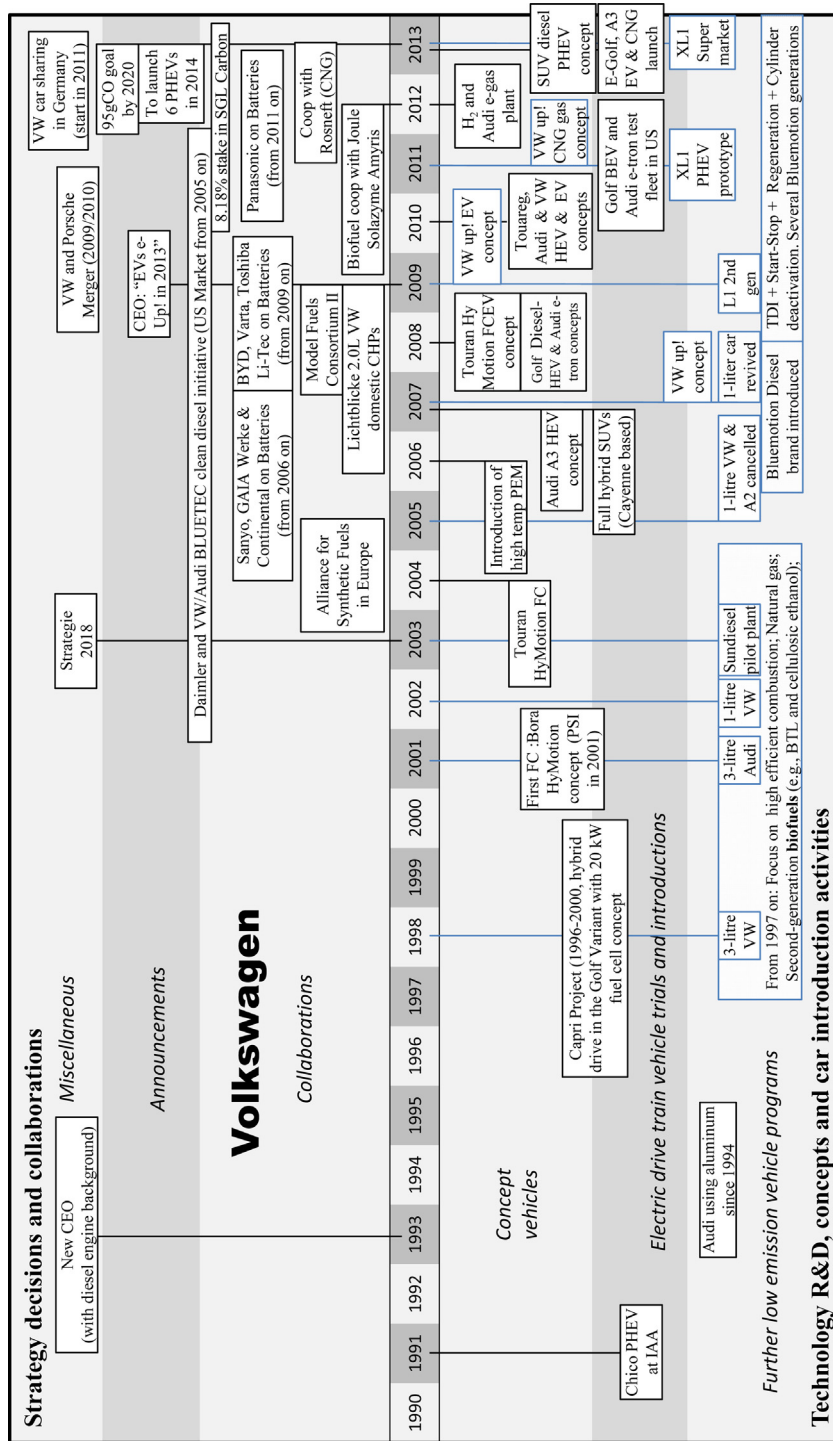


Fig. 5. Timeline for VW.

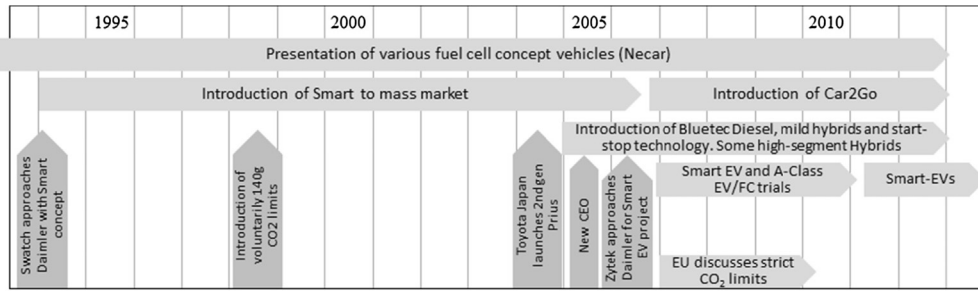


Fig. 6. Daimler timeline outlining discussed activities.

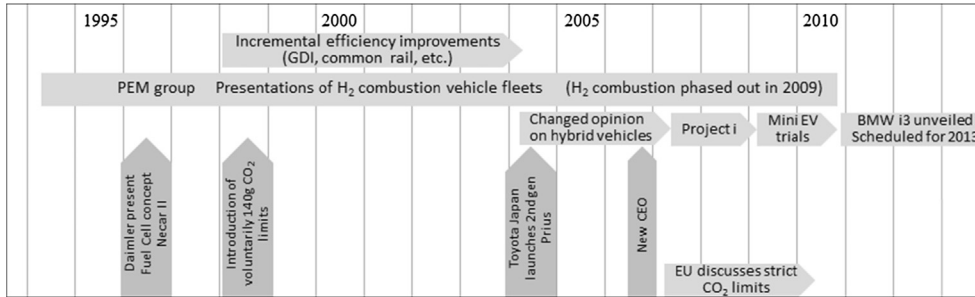


Fig. 7. BMW timeline outlining discussed activities.

when hydrogen was not seen as a winner anymore (Der Spiegel, 1996), major OEMs in Germany and Japan presented their respective solutions to deal with the CO<sub>2</sub> emission challenge. Surprisingly Daimler launched the Necar II hydrogen prototype, which triggered a new hydrogen/fuel cell hype, which however was mainly limited to Germany. However, this was reflected by a hype in media coverage that peaked in 2000/2001 (Konrad et al., 2012). At around the same time, hybrid vehicles such as the Toyota Prius and the Honda Insight were launched on the Japanese and US markets (Høyer, 2008).

The early 2000s were dominated by global economic crisis that had some influence on the production capacities and outputs of the automotive industry. So with regard to technology choices it was not until 2004/05 that major changes occurred. Toyota's success with the Prius hybrid vehicle and the launch of its second generation started to put significant pressure on the other automotive players. This was magnified by rising fuel prices. As a result, the changing perception of the hybrid

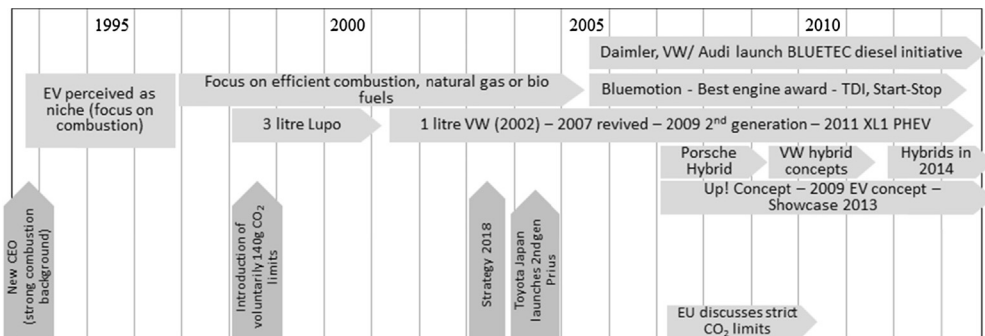


Fig. 8. VW timeline outlining discussed activities.

**Table 1**

Identified technology/solution related activities of the German car manufacturers.

Daimler	BMW	VW
<ul style="list-style-type: none"> <li>• Smart vehicle model launch</li> <li>• Bluetec diesel initiative</li> <li>• Smart EVs fleet trials</li> <li>• Battery production joint-venture</li> <li>• Car sharing scheme Car2Go</li> <li>• Electric B-Class vehicle launch</li> </ul>	<ul style="list-style-type: none"> <li>• Work on fuel cells</li> <li>• Hydrogen combustion vehicles</li> <li>• Engine efficiency improvements</li> <li>• Mini EV trials</li> <li>• i3 BEV and i8 PHEV launch</li> <li>• Carbon fibre materials</li> </ul>	<ul style="list-style-type: none"> <li>• 3 and 1 L/100 km vehicles</li> <li>• Focus on alternative fuels</li> <li>• Bluetec brand</li> <li>• Bluemotion and downsizing</li> <li>• Porsche hybrids launch</li> <li>• Introduction of EVs</li> </ul>

technology led to a ‘hybrid race’; this is testified by the significant increase in patents of hybrid technologies, HEV/PHEV prototypes being presented at various automobile exhibitions, and numerous announcements of HEV release dates (Budde et al., 2015). A wave of collaborations on these technologies among manufacturers and with suppliers could also be observed at the time (see timeline for the three manufacturers).

During all that time, even with ups and downs, hydrogen fuel cell technology continued to enjoy support from various government initiatives worldwide, such as the US Department of Energy’s Hydrogen Program. However, the inauguration of Steven Chu as the new US Secretary under President Obama in 2009 together with a reassessment of all technology options triggered a major change in perception of this technology. The US Hydrogen Program underwent major cuts and it was only the intervention of the Congress that prevented it from being cancelled altogether (Bakker et al., 2012a,b).

During that time (2009–2012) the global financial crisis hit, and governments in Germany, the UK, the US and elsewhere launched a swathe of different national support programmes for the automotive industry as part of broader economic stimulus packages, most of which had a technology focus. The “Nationale Plattform Elektromobilität” in Germany (Bundesregierung und deutsche Industrie, 2010) and the “Ultra Low Emission Vehicles initiative” in the UK (Department for Transport, 2012) had the aim to support the uptake of electric mobility in order to reach both environmental and industrial targets.

Since then, HEV/PHEVs and BEVs have dominated the debate while the hydrogen fuel cell technology has seen less hype, such as in the US White House Blueprint for a Secure Energy Future. In contrast, the introduction of the TESLA Model S, Chevrolet Volt, Nissan Leaf, Mitsubishi iMiEV and many more have kept battery technology firmly in the spotlight.

It is also worth noting that, despite the fact that post 2012/13 the focus is slowly shifting away again from small, fuel efficient vehicles towards bigger cars such as SUVs, PHEVs and BEVs still remain in the car manufacturers’ technology portfolios as short- or medium-term solutions and are steadily gaining momentum (see technologies in timelines), which suggests that a change in the current regime may be occurring. This is also reflected by a continuous reduction of fleet emissions of the three manufacturers studied here (based upon fleet emissions reported in the annual reports of those companies).

### 3.2. The German car manufacturers

In this section the activities of the German car manufacturers BMW, Daimler and VW in response to various events are analysed. Following the analytical framework in Section 2, a set of micro-level key activities related to low fleet emission technologies and solutions has been outlined and then put into relation with events that had happened at the automotive landscape and regime level. The analysis resulted in the identification of cases where activities on the micro-level were started, changed or discontinued as a consequence of regime and landscape pressures (Table 1).

These activities and the corresponding events are summarised in Figs. 6–8. For each of the activities outlined in Table 1 the following sections provide insights, in a narrative manner, into what triggered them and the extent to which policy played a role by discussing what happened at that time or earlier on the niche, regime and landscape levels.

### 3.2.1. Daimler's journey from the Necar I over Smart EVs to Tesla B-Classes

For a very long time Daimler was at the forefront of fuel cell research for automotive application. It was the move of the company's internal FC group from Dornier to the car section in the early 1990s that allowed Daimler to develop a number of FC prototypes and demonstrator vehicles. A few years later, in 1994 Daimler presented its first FC prototype Necar I (New Electric Car I), but it was the Necar II that would raise the profile of FC vehicles at that time (Budde et al., 2012).

Since that time Daimler has presented a variety of FC vehicles, including hybrids and versions with gas reformers. A collaboration with Ballard in Canada led to the purchase of a stake in Ballard by Daimler (together with Ford) in 1997, and in 2007 to the total acquisition of the Ballard's automotive FC division. This meant that since the early 1990s Daimler had been accumulating substantial know-how and R&D infrastructure in hydrogen fuel cells (Budde et al., 2012).

Around the millennium this had led to high expectations with regard to the commercial launch of FCEVs. However, although Daimler announced in 1999 that there would be 100,000 FCEVs in 2004, the application of the fuel cell technology never went beyond demonstrator programmes or small series production (Budde et al., 2012). Even though at the end of the 1990s fleet emission targets started being discussed at the EU level, they only led to improvements of internal combustion engine efficiencies.

In the early 1990s Daimler introduced the Smart brand, providing small and efficient cars for the urban environment. But this development was not an indirect effect of the California ZEV programme. Instead the development and introduction of the Smart had been proposed and initiated by Swatch, reflecting their vision of future mobility. In 1994 Daimler took over Volkswagen's engagement in Nicolas G. Hayek's micro compact vehicle project, aiming to provide a small city vehicle (Die Zeit, 1994). The Smart fortwo, a small two seat vehicle was brought to market in 1998, but as Hayek's vision of a small and energy efficient vehicle that could be used for car sharing had not been satisfied nor shared by Daimler, Hayek decided to leave the joint venture and Daimler became sole owner of Smart. Although Daimler launched a number of vehicles under the Smart brand, the initiative only generated losses (Lewin, 2004; Steger et al., 2007; The New York Times, 1999).

However, the Smart brand contributed to decreasing Daimler's average fleet emissions, down to around 180 g CO<sub>2</sub>/km in 2005 from 230 g CO<sub>2</sub>/km in 1995. At this point in time the disruptive change (the Smart vehicle meant for Daimler the introduction of completely new distribution and supply chains and the engagement with a new customer segment) from the view point of Daimler had been induced by an external actor. But the company was not entirely backing this vision and pressures on the landscape level were not strong enough. The impact of this project on Daimler's direction was negligible.

The same can be said about the Smart EV trials that were induced by actors external to the company (Zytek Automotive, 2013). Being interested in gaining experience in the application of electric vehicle technologies, the British company Zytek that was recently acquired by Continental had approached Daimler (Zytek Automotive, 2014) and proposed and delivered the first generations of the Smart EVs, covering all expenses.

This development fell into a time (2004/05) when there was already significant pressure on the existing regime from the landscape level. There were consumer concerns about fuel costs, the effects of carbon emissions as well as the discussion about legally binding fleet emission targets. Also the introduction of the second generation of the Toyota Prius Hybrid that was well received in the US market put pressure on the entire automotive industry, including Daimler. Daimler however, only responded with the market introduction of incremental technologies such as start-stop, efficient diesel engines and mild hybrids. It also introduced, together with Volkswagen and GM, its Bluetec Diesel branding (see timelines).

Although Daimler had already experienced pressures on the landscape level, it was the externally induced Smart EV trials that provided a push towards the mass introduction of battery electric vehicle technologies, a novelty for the company. This fell also in a time when a new CEO (2005) had been appointed who launched significant restructuring programmes. As a result, while past developments had often ended in the presentation of concept vehicles only, these new developments (see Fig. 6) finally led to a continuous journey towards different types of electric vehicle technologies.

While the first Smart electric vehicle components were still provided by [Zytek Automotive \(2013\)](#), the newest generations were using batteries, battery systems and motors from subsidiaries that Daimler created in the late 2000s. Together with Evonik, a specialist in chemicals, it formed a joint venture for batteries, called 'Li-tec' and one for battery management systems ([Handelsblatt, 2008](#)), called 'ACCUmotive' ([Handelsblatt, 2009](#)), and with Bosch it formed a JV on electric motors, called 'hubject GmbH' ([Daimler, 2012](#)). Before that, in 2009 Daimler bought stakes in TESLA, which supplied the batteries for the 2nd generation of electric Smart vehicles ([Spiegel Online, 2009a](#)). To ensure economies of scale for the JVs with Evonik, the batteries were also offered to other OEMs such as Renault/Nissan. Furthermore, in the early 2010s Daimler announced a collaboration with Toyota in the domain of fuel cells ([Green Car Congress, 2010](#)) and more collaborations with carbon and composite manufacturers.

At the time Daimler's competitors were receiving significant media coverage in relation to their battery EVs, especially BMW with the i3 and i8 models and Tesla with the model S. Daimler had to respond accordingly, relying again on external help. In parallel to the launch of the BMW i3 it surprisingly launched an all-electric B-Class that slightly outperforms the i3 in range, price and size – though it features an electric vehicle technology developed by Tesla ([Green Car Congress, 2012](#)).

To summarise the Daimler case, while pressures on the landscape level were always driving some developments of battery, hybrid or fuel cell technology, in general there was no actual move to bring them to the mass market. If work on technologies or solutions that were novel for the company were started, then it mostly focused on incremental improvements based upon past work, such as that done on engine efficiency improvements.

Disruptive change was brought about only by the appearance of external actors, as in the case of Smart and Smart EV. These actors led to the introduction of novel technologies and vehicle segments. But they could only succeed because there was already sufficient pressure on the landscape level backing these developments.

### 3.2.2. *BMW's journey from burning hydrogen in engines through project i to lightweight electric vehicles*

During the early 1990s BMW's ZEV regulation-driven experiences with alternative vehicle propulsion technologies were unsatisfactory, but in 1996 the company established serious hydrogen research activities. This happened at a time of hydrogen disappointment in the automotive sector ([Der Spiegel, 1996](#)). Daimler, BMW's main competitor, had presented its Necar hydrogen fuel cell prototypes and hence, instead of regulatory pressure it was the action of its main competitor which had led to the establishing of a fuel cell research group ([Buddle et al., 2012](#)). Furthermore, though research work also focused on PEM fuel cells and later SOFC fuel cells, in 1998 BMW presented the 750hL, a large executive sedan that was not powered by fuel cells but instead burned the hydrogen in a conventional combustion engine. The vehicle only featured a 5 kW fuel cell that was used as auxiliary power unit for various electronic systems in the vehicle ([VDI Nachrichten, 2010](#)).

Since then, BMW built a small series of more than 100 of these hydrogen combustion engine vehicles. These were used at various events ([Spiegel Online, 2001](#)), such as the World Exhibition in 2000 in Germany and a number of demonstrator programmes where the vehicles proved themselves running for a total of over 4,000,000 km. A petrol fuelled car that used a solid oxide fuel cell auxiliary power unit was also presented. The fuel for the fuel cell was obtained by reformation of the petrol. But these vehicles were not a move towards new technologies as they still relied on combustion engines – these solutions were still part of the existing regime. On the other hand, using fuel cells to deliver power to the electronics of the car was a way for BMW to gain knowledge in the application of this technology.

However, the above-mentioned vehicles never reached the market. Although there were discussions about fleet emission targets at the EU level and BMW announced in 2002 that it would bring its hydrogen combustion vehicle to market ([Auto Bild, 2002](#)), this never went beyond the status of demonstrator. There was no attempt yet by BMW to bring novel vehicle electrification technologies to production. Moreover, since the beginning of the 2000s, BMW focused its efforts on the introduction of a variety of engine efficiency improvements and on the wider use of diesel in the fleet, both of which led to a slow but steady decrease in average fleet emissions – an incremental solution. Furthermore, hybrid and electric vehicle development at BMW did not intensify over this period of time. BMW did

not attempt a disruptive change of their vehicle propulsion technology, nor was this even mentioned in the company's annual reports.

This changed in 2005/06, coinciding with the success of Toyota's Prius and rising fuel prices, causing customers to demand similar solutions ([Der Spiegel, 2005](#)). Until then, only hydrogen combustion technology featured in the annual reports as a future solution for low emission vehicles. In contrast to that, from 2005/06 onwards, hybrid vehicle technology started to feature in the annual reports as well. Around that time, collaboration with GM and Daimler–Chrysler was announced in order to develop a hybrid system to compete with the Japanese manufacturers. Additionally, in 2006/2007 BMW intensified its hydrogen combustion vehicle activities by leasing out 100 vehicles to the public and with incremental improvements such as the recuperation of energy to its lead acid battery ([Spiegel Online, 2006b](#)). Still, BMW did not provide any real hybrid vehicle solution. It continued to concentrate on the technologies it was familiar with – the internal combustion engine and its efficiency – and this, in spite of the increasing pressure on the landscape level created by discussions on mandatory CO<sub>2</sub> fleet emissions standards in the European Union to replace the existing voluntary agreements.

However, after the selection of a new CEO in 2006, in 2007 (a very successful year for BMW, with no signs of the financial crisis yet to come) BMW initiated 'project i' under its so-called 'number ONE strategy'. This project was launched to review the future technology options. It was this project that triggered a significant change in the long-term technology strategy of BMW with disruptive consequences on its technology choices ([BMW Group, 2009](#); [Spiegel Online, 2013a](#)).

Shortly after the review had finished, BMW stopped the hydrogen combustion vehicle programme that it had been promoting for so many years and instead announced a series of changes ([FOCUS, 2009](#)), including the launch of a Mini EV trial fleet, collaboration with SB LiMotive on batteries and the creation of a Joint Venture with PSA (Peugeot/Citroen).

The results from these trials led in 2010 to the announcement that BMW was planning to develop and produce a BEV for the mass market. BMW's announcement meant that the company was now embarking on a journey towards electric vehicles ([Der Spiegel, 2010](#)).

In the early 2010s, after a number of competitors brought their PHEVs and BEVs to market, BMW presented its Megacity Vehicle (BMW i3), a small lightweight BEV vehicle built in Leipzig that was commercialised at the end of 2013 ([Der Spiegel, 2010](#)). With an entirely new production plant built to produce the i3, BMW has clearly committed to this technology.

During 2011 the acquisition of SGL Carbon, the supplier of lightweight materials for the i3 and i8 was also announced ([Spiegel Online, 2011, 2013a](#)). In 2012/2013, a time when the number of HEVs/PHEVs in BMW's portfolio was limited, BMW also agreed to collaborate with Toyota on fuel cell systems, lithium-air batteries, lightweight technologies and the electrification of vehicles ([Spiegel Online, 2012](#)).

To summarise the BMW case (see [Fig. 7](#)), while pressures on the landscape level were always driving some developments of vehicle electrification technologies; there was no actual move to bring them to the mass market until the introduction of a new CEO in 2006. Most of the work focused on the known internal combustion engine technology – only the fuel being replaced with hydrogen. It can therefore be stated that the concept and trial vehicles were still largely based upon 'past' knowledge.

Despite the significant pressure at regime level brought by the success of the Prius hybrid vehicle and the serious discussions of mandatory fleet emission standards, it was not until the 'project i' was initiated and a review of BMW's long-term technology strategy conducted, triggered by the appointment of the new CEO, that BMW decided to focus on lightweight and battery vehicle technologies ([BMW Group, 2009](#)). The company has since embarked on a path towards a disruptive change of their technology and product portfolio.

### 3.2.3. VW's steady path meeting emission limits

Even though VW executed some trials on EVs, PHEVs and FC vehicles in the 1990s, its vehicle propulsion technology research was mainly focussed on highly efficient combustion engines and especially diesel engines, as well as the use of bio fuels. While BMW and Daimler had presented their solutions for low emission transport, VW presented its Lupo 3L with a fuel consumption of 3l/100 km in 1998 ([Der Spiegel, 1998](#)), followed in 2002 by the announcement of a 1 L vehicle ([Spiegel Online, 2002](#)), that was not introduced to market at that time. This work was strongly supported by the CEO who had a background in combustion technology and especially diesel engine engineering. However,



development of the vehicles was soon scrapped due to low demand (similar to what had happened to the Audi A2) before 2005 (Spiegel Online, 2005b). In comparison to BMW and Daimler, VW made fewer public announcements with regards to alternative vehicle concepts.

During 2005 the success of the Prius and rising fuel prices coincided with the creation of the collaborative brand Bluetec for Diesel combustion engine vehicles – together with Daimler and GM (Spiegel Online, 2006a). It can be seen that during these times VW was still sticking to its traditional, internal combustion engine based products.

Similar to its German competitors, VW reacted to the success of the Prius in the late 2000s with the development of low emission engines. This led very early on to the development of downsized engines such as the 1.4 litre TSI turbocharged that won Engine Awards for 7 consecutive years since 2006 (Green Car Congress, 2013; Spiegel Online, 2005a). The micro vehicle up!, which is similar to the Smart fortwo but a four-seater, was introduced in 2009 (Spiegel Online, 2009b). Furthermore, the 1 L vehicle project was re-launched again in 2007 (Green Car Congress, 2007), leading to a number of prototypes, with the last one in 2013 called XL1 Super Efficient (Spiegel Online, 2013b). In addition to that VW pursued the development of biofuels and launched its own production facilities in the early 2010s.

Until recently, no significant changes in technology could be observed, despite the mandatory emission regulations introduced in the EU. This is explained by the fact that, unlike the rest of the German manufacturers, these policies were less of a threat to VW as it had historically served the market with smaller vehicles. As a result VW has always been on track towards meeting average fleet emissions targets (120 g CO<sub>2</sub>/km by 2015 and 95 g CO<sub>2</sub>/km by 2020). As a result, regulation did not create sufficiently strong pressure to introduce disruptive vehicle electrification technologies such as EVs at VW. However, VW has recently started to develop EV concepts such as the EV 'VW up!', which was introduced in 2014, probably responding to the electric vehicle activities of its competitors.

It is worth noting that within the VW family it is Porsche that first started work on electric propulsion in 2007 (Spiegel Online, 2007), developing hybrid vehicles in response to the request for 'green' SUVs from its customers, collaborating with Sanyo in Li-ion batteries and Continental for the delivery of the necessary components (Green Car Congress, 2009).

To summarise (see Fig. 8), VW's technology choice of highly efficient diesel technology had been able to satisfy landscape pressures such as emission regulations and high fuel costs. Therefore in contrast with the other manufacturers it is difficult to identify a significant move towards electric vehicle technology yet. However, there are recent signs that VW has finally taken this step, although the exact reasons are hard to infer yet.

#### 4. Conclusion

This study has examined on a micro-level what has influenced the low emission vehicle technology related activities of the three main German car manufacturers. Based upon the analytical framework chosen (see Fig. 1), major changes in the activities of these firms that went far beyond business-as-usual were identified and then put in relation to what had been happening at the regime and landscape level at that time. The goal was to identify triggers for these activities.

To summarise, the analysis has led to the following insights.

For all three manufacturers, activities related to niche technologies that were new to them only occurred when actively introduced by external actors such as collaborators or induced by internally disruptive events such as new CEOs. This is in line with the finding by earlier studies (Benn et al., 2006; Howell and Higgins, 1990; Howell et al., 2005) that 'innovation champions' or 'change agents' play an important role with regard to disruptive changes.

However, in order for change agents to initiate niche related activities, the presence of sufficient pressure at the regime and landscape level is a necessary condition. One example of such pressure is already the discussion of mandatory fleet CO<sub>2</sub> emission targets to replace the automotive industry's voluntary agreements. As already found by earlier studies (Budde et al., 2012; Konrad et al., 2012; Wesseling et al., 2013), in the absence of significant external pressures the German car manufacturers did not seek niche technologies. Such pressure, where present, can also be created by consumers' demands and the success of competitors.

Moreover we find that the influence of regulatory policy on the selection of particular disruptive technologies by the automotive industry is limited. Policy programmes that were supporting one specific niche technology did not make all three car manufacturers work on this one technology but instead they continued to work on the technologies that were familiar to them. The industry by itself determines the path or technology they choose and this can differ across companies even though they are part of the same socio-technical system. All three German players studied were affected by the same trends and policies – still, they came up with different technology solutions. And on the world scale, Toyota had chosen hybrids; Nissan, Tesla and BMW went for battery electric vehicles; and now, Toyota is moving back towards fuel cells – a solution which Daimler is moving away from, in favour of battery electric vehicles. Clearly there is no obvious winner yet.

Finally, it appears that, in the absence of external or internal change agents, car manufacturers typically respond to regime and landscape pressures such as fleet emission regulations with incremental technologies created through the combination of internally available solutions.

Although the observations we have made in our study are general in nature and the sample on which they are based is relatively limited, the results still provide valuable insight into the effect that government policy has on the automotive industry – and what limitations exist. Our observations make it clear that in the case where a transition that requires a significant alignment of the regime is favoured by policy makers, the creation of policy incentives or pressures on the landscape level might not be enough to induce such an alignment due to the existing circumstances of the individual actors and organisations. The internal conditions at these companies might not be supporting such a change, either due to lack of internally available knowledge or the lack of support within the organisation.

This does not mean that policy making is obsolete. It might not influence what particular technologies (combustion engine efficiency, lightweight materials, BEV, PHEV or FCEV) a company will choose in the end, but it can create landscape conditions – or pressures – that support the work of internal change agents whose disruptive propositions are more likely to be accepted. Hence under the right conditions niche related activities become less of a disturbance to the company's status quo and more of a welcomed solution.

To conclude, we propose that policy makers should ensure that the industry (that often has already chosen and often is already developing a certain technology) is supported in its efforts to gain a competitive advantage with their chosen solution. Therefore, financial support should not have the purpose to push the industry towards a certain technology over others, but instead, for example for being technology neutral, it should support the R&D of the disruptive technologies that the industry itself selects. At the same time it is essential that policy makers should maintain the non-financial policies such as regulations and standards that create the landscape conditions that destabilise the regime if it does not support the ultimate policy goals in terms of fuel efficiency and emission reduction.

With regards to the presented framework, it has to be mentioned that different interpretations are possible due to the nature of the MLP and especially the soft boundaries between its different levels. Still, although the MLP is perceived to have a number of limitations (Geels, 2011), it provides a useful framework for a structured discussion of the way, in which micro-level activities contribute to transitions.

## Acknowledgments

We gratefully acknowledge funding from: the Grantham Institute (Imperial College London) and the Climate Knowledge and Innovation Community (Climate-KIC of the European Institute of Innovation and Technology EIT) for Christoph Mazur; the UK EPSRC through the grant “SUPERGEN 14: Delivery of Sustainable Hydrogen” for Marcello Contestabile and a Career Acceleration Fellowship for Gregory Offer, award number EP/I00422X/1. Furthermore many thanks to Jacco C.M. Farla and the three anonymous reviewers whose advice greatly improved this article.



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